THE RELATION OF THE DORSAL ROOTS OF THE SPINAL NERVES AND THE MESENCEPHALON TO THE CONTROL OF THE RESPIRATORY MOVEMENTS

BY

HELEN COPELAND COOMBS

A DISSERTATION

Submitted in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy in the Faculty of Pure Science, Columbia University, New York City

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The general history of the work upon the nervous mechanism of respiration begins with the experiments of LeGallois and Flourens in the early part of the nineteenth century. In 1811 LeGallois (1) demonstrated that after transection below the medulla, all respiratory movements of the body cease with the exception of movements of the mouth, which cease also after section of the medulla. Flourens (2) amplified and confirmed this work (1842–1851). His experimental procedures began by removing the cerebrum, then the cerebellum, then the corpora quadrigemina of an animal (rabbits and pigeons were mostly used). Respiration persisted until sections of the medulla were made, then it failed. Reversing the operation and beginning with the lumbar spinal cord, making successive sections upward he found that

> In destroying the costal spinal cord, the rise and fall of the sides diminished gradually and when he had finished, had entirely disappeared.

As he continued to make sections upward, respiration was maintained, although with difficulty, by the diaphragm until the origin of the nerves of the diaphragm was reached when with their section and consequent cessation of the movements of the diaphragm, all effective respiration stopped, for the yawnings of the mouth and glottis which alone survived had no effect. He then proceeded in a reverse manner, removing the medulla by transverse sections from front to rear. The yawning movements disappeared first; then the dilation of the nostrils; the inspiratory movements of the trunk alone survived and finally these failed also. These experiments appear to indicate that the spinal respiratory nerves are unable of themselves to maintain rhythmic respiratory movements but are dependent on the action of a central coördinating mechanism situated somewhere above the lower end of the medulla oblongata.

Volkmann (1842), Longet (1847) and Schiff (1858) (3) showed that the central respiratory mechanism is a double organ which can be divided by a median longitudinal section without causing the death of the animal; and Longet, and more particularly Schiff, endeavored to show that this central mechanism is located in the nucleus of the grey matter in the alae cinereae in the lower part of the bulb, on each side beneath the floor of the fourth ventricle, and that the paths by which the impulse is conducted thence to the spinal cord run in the lateral bundles,

> Unilateral section of which at the lower level of the bulb, or at the level of the second or third cervical vertebrae, suffices to produce respiratory paralysis on the same side.

In opposition to this view, Brown-Sequard (4) enunciated his doctrine of "inhibitory centers." He showed in 1860 that if young animals were kept alive by artificial respiration for some time after section of the spinal cord below the medulla, when the artificial respiration was stopped, coördinated movements of the thorax and diaphragm might still be observed for a time. He therefore concluded that the center for respiration was not sharply localized in the medulla but extended throughout the spinal cord. The effects of section of the spinal cord below the medulla, he attributed to "inhibition" of these centers following the lesion of the cord, and he compared the phenomena with those of spinal shock.

This doctrine, including that of spinal respiration, was later presented in fuller form by Langendorff (1887) and Wertheimer (5) who observed that the respiratory muscles of the trunk could sometimes be made to contract after separation of the cord from the bulb in animals poisoned with strychnine, in animals with the cord artificially cooled or subjected to prolonged artificial respiration. Wertheimer declared that such contractions showed the power of the spinal cord to originate respiratory impulses.

Such an hypothesis has, however, been too often refuted to be at all acceptable at the present time. Schiff, in his early exposition of respiratory hemiplegia, demonstrated that section of the spinal cord at the level of the second and third cervical vertebrae paralyzes the respiratory mechanism.

Porter (6), in his study of the innervation of the diaphragm, followed a similar line of reasoning. He showed that since hemisections of the spinal cord above the phrenic nuclei do not inhibit the diaphragm

on the same side, it follows that two hemisections altogether separating the phrenic nuclei from the bulb do not inhibit the diaphragm on their respective sides. In other words, the arrest of thoracic and diaphragmatic breathing in consequence of the separation of the phrenic nuclei from the bulb is not an inhibition. But one explanation of the arrest is then possible; the phrenic nuclei effect no respiratory discharge after their separation from the bulb because they receive no impulses and cannot originate them. Hence the cells for the discharge of respiratory impulses are situated above the calamus scriptorius and not in the spinal cord.

In addition to this, Starling (7) has pointed out that cells from which the nerve fibers go to the respiratory muscles can, like the motor cells of other parts of the organism, be affected by impulses reaching them along various paths. Their normal activity in respiration depends upon impulses from the medulla but they can also be affected along other tracts derived ultimately from the posterior roots, at the same or higher levels of the cord.

Hering (8) has concluded that after division of all the dorsal roots of the frog, the motor cells cannot discharge when removed from peripheral stimulation, and in the case of respiration, he is convinced that

> The normal rhythm of respiration is bound up with the integrity of the accompanying centripetal nerves.

Of late years, however, the relative importance of the dorsal roots of the spinal nerves in the maintenance of respiration has been overlooked; perhaps the refutation of the ideas of "spinal respiratory centers" had a discouraging effect, certain it is that little or no mention of the dorsal roots and their connection with respiration is made in present-day literature. The best pronouncement with which I am familiar has been made by Luciani (9) who thus epitomizes their activity:

> When the auto-regulation by means of the vagi is suppressed, an abnormal type of respiratory rhythm appears which, although it provides for a degree of pulmonary ventilation sufficient to maintain life, must yet be termed dyspneic since it is not obtained without useless expenditure of energy. Under these conditions it seems to us probable that a self-regulation comes into play due to the rythmical and alternate excitation of the sensory paths of the inspiratory and expiratory muscles.

The question has often arisen as to whether there is a mechanism for the integration of the respiratory movements higher than the medulla. The opinions of the various authors who have written upon this subject appear to be somewhat divided.

Starling (7), in citing the work of Rosenthal and Marckwald, states,

> In the rabbit, section through the upper part of the medulla oblongata, separating the respiratory center from the higher parts of the brain, is equally with out effect on the depth and rhythm of the respiratory movements. A great change is observed, however, if the vagi are subsequently divided under these conditions.

Nikolaides (10) says that in rabbits, isolation of the medulla oblongata from above causes almost the same effect as double vagotomy.

Luciani (9) states that

> When the brain is extirpated to the level of a plane which passes along the inferior limit of the pons, or when the section is made at the level of this plane, it will be seen that after temporary disturbance, the animal continues to breathe in a regular, perfectly coördinated manner.

H. Newell Martin (11) found that

> On stimulation of the mid-brain of the rabbit, close to the iter and beneath the corpora quadrigemina, there is a respiratory regulating center similar to that of the corpora bigemina of the frog.

Marckwald (5) found that on blocking off the respiratory center from the brain above by the injection of paraffin into the common carotid, if these higher paths are cut off, the respiration remains regular, although deep, and perhaps in the course of time tends to resume its original type; but if the vagi are also sectioned, the respiration is entirely changed; periods of rapid breathing alternate with periods of complete cessation until the animal dies.

From the literature here quoted it will be seen that division of the vagi, in connection with section at the level of the corpora quadrigemina has been considered. The possible relationship of the dorsal roots of the spinal nerves has, however, been given no attention. I have therefore performed a series of experiments with a view to determining whether there is a possibility of such a relationship.

These experiments have extended over more than a year, and include results upon about forty cats. These animals were first etherized and then tracheotomized and ether was given by means of a tracheal cannula. Tracings of both costal and abdominal respiration were taken by means of Crile stethographs attached to Verdin recording tambours. I will consider the results first of section of the dorsal roots of the spinal nerves alone, then at the level of the posterior corpora quadrigemina alone and finally the effects of the two operations together.

After a control tracing of normal respiration (under ether) was taken, laminectomy was done and the dorsal roots of the spinal nerves were then sectioned, sometimes in both thoracic and cervical regions and sometimes in the cervical region only. If the dorsal spinal roots are cut in the thoracic region alone there is a diminution of costal respiration although abdominal respiration remains unaltered and the rate is very little changed; if the cervical dorsal roots also are involved, independent costal respiration disappears, such costal respiration as is present being passive and induced by the abdominal respiration as the tracing of March 2, 1918 (fig. 1) shows. Such respiration is slower than normal but the general character of the respiratory curve is not altered. When the dorsal roots are cut in the cervical region alone, thoracic respiration is not greatly changed. An animal whose dorsal spinal roots have been divided aseptically may be kept alive for an indefinite period. Such an operation, indeed, is analogous to the condition found in some cases of tabes dorsalis in which the functions necessary for the maintenance of life may be performed adequately enough although precision of movement is lacking.

It is of interest to observe in connection with the experimental work the remarkable compensatory power of the individual dorsal roots. If, for example, in sectioning the dorsal spinal roots in the thoracic and cervical regions, a single root on either side be left intact, costal respiration remains much better than the general severity of the operation and the number of roots cut would lead one to suppose possible. A study of the nervous system impresses one more and more with its remarkable adaptive facility in the rearrangement of channels for the conduction of nervous impulses when the normal ones are cut off, and this is particularly exemplified in the conduct of the dorsal spinal roots of the thoracic region of the cord.

Following is a protocol of an experiment in which the dorsal roots were divided.

March 2, 1918. Male cat (fig. 1).
Ether, tracheotomy.
Laminectomy.
Control tracing of respiration taken (part 1).
Dorsal spinal roots cut from third cervical to lower thoracic.
Respiration tracing taken (part 2).

In this experiment, the significant factor is the complete cessation of an active form of costal respiration, such slight passive movements as

are present being the results of the active diaphragmatic respiration. The rate, however, is not greatly altered.

It is evident that in the maintenance of respiration a central integrating mechanism is of first importance. We are well aware of the necessity of the integrity of the respiratory center in the medulla for the initiation of respiratory movements, but is there no mechanism for the integration of nervous impulses concerned with respiration higher than

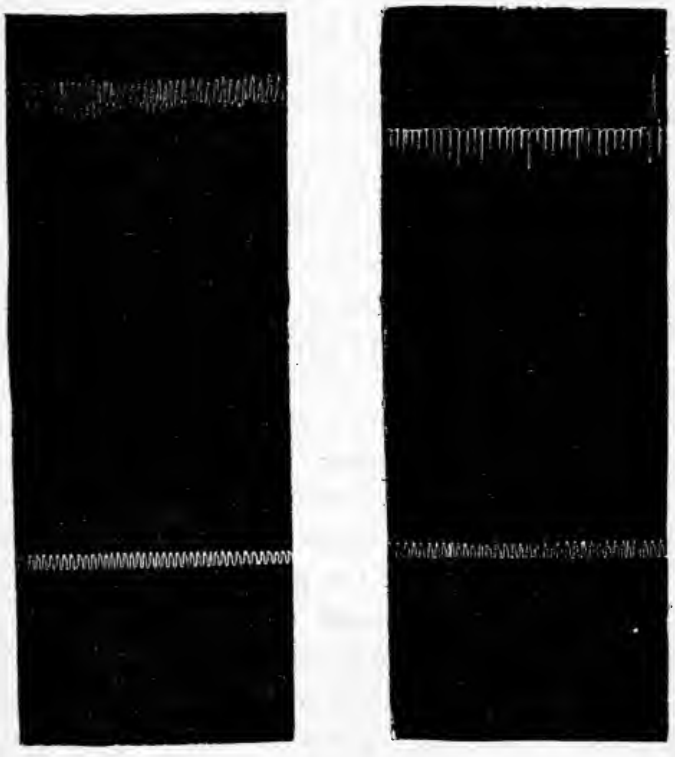

Fig. 1

Part 1. Respiration after laminectomy has been performed.

Part 2. Respiration after section of the dorsal roots of the spinal nerves from the third cervical to the lower thoracic. Upper tracing represents costal lower abdominal respiration.

the medulla? In other words, if all portions of the brain above the medulla were removed, would respiration proceed in the same manner as before?

In the technique for the operation of section of the brain stem above the medulla, the carotids were first tied off to prevent excessive hemorrhage and the animal was then either decerebrated by removing the hemispheres from the cranial cavity or a trephine opening was made

over the occipital ridge and the corpora quadrigemina were sectioned through it.

I have found that sections in front of the corpora quadrigemina and between the anterior and posterior corpora produce no effect upon respiration; when, however, the section cuts into or behind the posterior corpora quadrigemina, there is a change in the character of the respiration. It appears to become slower and less regular than the normal type; still, it is hardly of a gasping character and maintains a very fair type of ventilation.

The difference in conduct between the results of this operation and that of complete section of the dorsal roots in the thoracic and cervical regions is one of degree rather than kind. In the latter case, a few channels for sensory impulses may remain above and below the sections—and we have mentioned the compensatory power of the dorsal roots in this respect—while the conduct in the former case implies a total lack of these sensory impulses.

In this connection, we cite the protocol of

March 16, 1918. Male cat (fig. 2).
Ether, tracheotomy.
2.00 p.m. Normal respiration (part 1).
2.45 p.m. Carotids tied off, then section behind corpora quadrigemina.
3.30 p.m. Good respiration, see tracing (part 2).

Such respiration as this gives no indication of the dyspnea which some authors have found and does, to some extent, resemble the slowing obtained after double vagotomy. I have observed at various times, however, that if after section is made there occurs a hemorrhage into the fourth ventricle, which causes a clot producing pressure upon its floor, then dyspnea always occurs. But if no such hemorrhage occurs, dyspnea is not present except in a very slight degree.

As I have previously indicated, the spinal cord has not been regarded as an important factor in respiration, during late years, and even when the possibility of spinal respiratory centers was under consideration few authors ever expressed the idea of a relationship between the dorsal roots and these spinal centers. It has been shown in a previous paper (15) that the dorsal roots undoubtedly play an important part in the sensory mechanism of costal respiration and that fibers concerned with afferent impulses pass up the spinal cord; our present work has served to confirm these findings and to extend them. Moreover, section of the brain stem at the level of the posterior corpora quadrigemina produces

immediate and lasting effects upon the respiration. Since the mesencephalon contains afferent and efferent fibers from the spinal cord, the question presents itself as to possible relationships between the dorsal roots of the intercostals and the mesencephalon as shown by the effect of section at the level of the posterior corpora quadrigemina and the dorsal roots of the spinal nerves in the cervical-thoracic region. Following is a protocol of such an experiment.

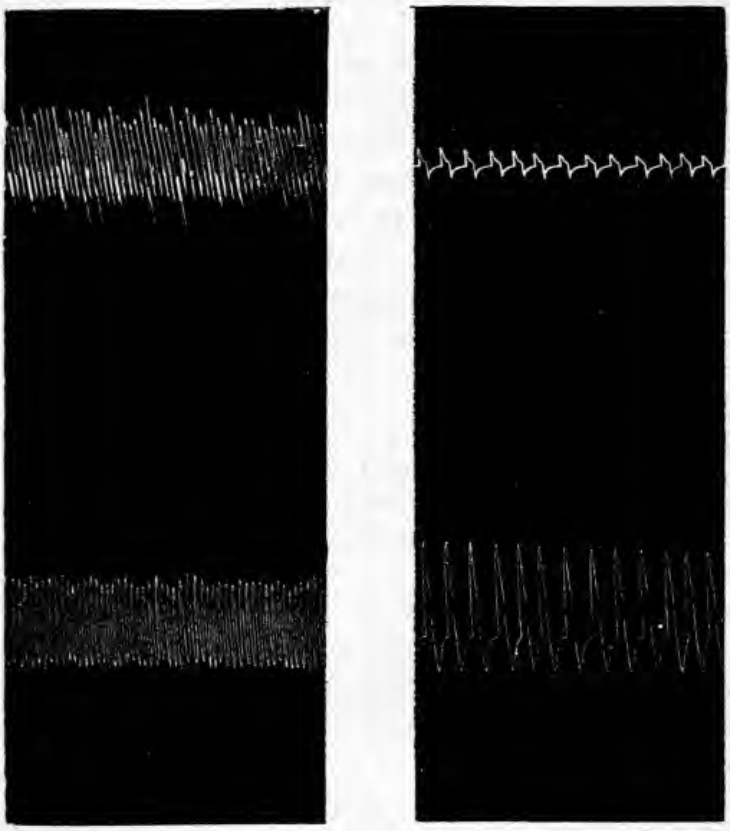

Fig. 2

Part 1. Normal respiration.
Part 2. Respiration after section behind the posterior corpora quadrigemina. Upper tracing represents costal, lower abdominal respiration.

July 13, 1917. Female cat (fig. 3).
Ether, tracheotomy, laminectomy (part 1).
2.40 p.m. Carotids tied off.
2.45 p.m. Decerebration.
2.55 p.m. Section behind the corpora quadrigemina (part 2).
3.20 p.m. Dorsal roots in cervical and upper thoracic regions cut (part 3).

From this experiment an interesting phenomenon may be observed, namely, that *after section of the posterior corpora quadrigemina, subsequent section of the dorsal roots is followed by no additional effects.* Such a finding leads one to conclude that certain of the sensory impulses at least, if not all connected with respiration from the dorsal roots of the

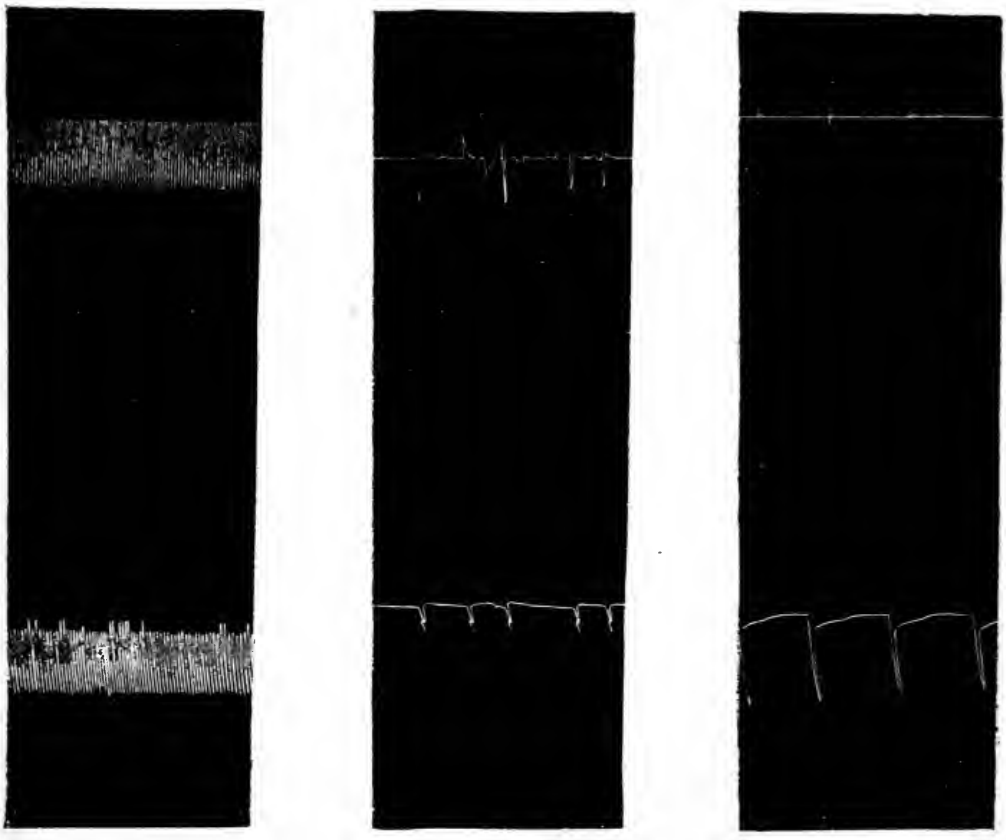

Fig. 3

Part 1. Normal respiration.
Part 2. Respiration after section behind the posterior corpora quadrigemina
Part 3. Respiration after section of the dorsal spinal roots in the cervica and upper thoracic regions. Upper tracing represents costal, lower abdomina respiration.

intercostals, pass through the posterior corpora quadrigemina since the difference in severity between the results of the two operations is about the difference that might be expected between total and partial elimination of the afferent impulses from the dorsal roots. Moreover, the fact that section of the dorsal roots after section of the corpora quadrigemina produces no change in the character of respiration shows that the entire effect was obtained by the first division.

Section of the dorsal roots before the corpora quadrigemina are sectioned does leave some additional effect to be gained by the latter operation, as the following protocol shows.

March 5, 1918. Male cat (fig. 4).
Ether, tracheotomy, laminectomy.
2.45 p.m. Control tracing (part 1).
3.05 p.m. After section of the dorsal roots in the thoracic and lower cervical regions (part 2).
3.30 p.m. After section of the posterior corpora quadrigemina. Note the Cheyne-Stokes respiration (part 3).

From this experiment it is evident that there are still some afferent intercostal impulses going through until the posterior corpora are divided—not until then are all intercostal impulses cut off.

Such corroborative detail points strongly to the probability of the existence at the level of the posterior corpora quadrigemina of some station closely related to the integration of the afferent impulses from the respiratory "cage."

While certain of the motor impulses concerned in the skilled movements of respiration must originate in the motor areas of the cerebrum it is hardly likely that these are called into play during normal respiration or during anaesthesia; and on the other hand, a purely medullary type of respiration due to the movements of the diaphragm alone is not normal either. I believe, therefore, that sensory fibers from the dorsal roots of the spinal nerves from the intercostals travel up the brain stem as high as the level of the posterior corpora quadrigemina, where some connection with the descending motor fibers is effected. In other words, the dorsal spinal nerves and a region for the integration of respiratory impulses at the level of the posterior corpora belong to the same system. The fact that vagi and mesencephalon are unrelated in this manner is what makes section of the vagi in this connection so much more fatal than section of the dorsal roots—a relation which will be discussed in a subsequent paper.

The time element concerned in section of the dorsal roots and the corpora quadrigemina may also be considered. It is well known from clinical evidence that people in whom accident or disease has destroyed the dorsal spinal nerve roots are able to support life very adequately. Stewart (12) has cited the case of a man in whom all the ribs became completely immovable from disease of the spine in the lower cervical region. He was able to lead an active life and carry on his business although he breathed entirely by means of the diaphragm and abdom-

inal muscles. Whether an animal in which both the dorsal roots and the corpora quadrigemina were destroyed could maintain life very long, I am not prepared to state; but experimentally, under anaesthesia, good respiration may be maintained for several hours subsequent to these operations.

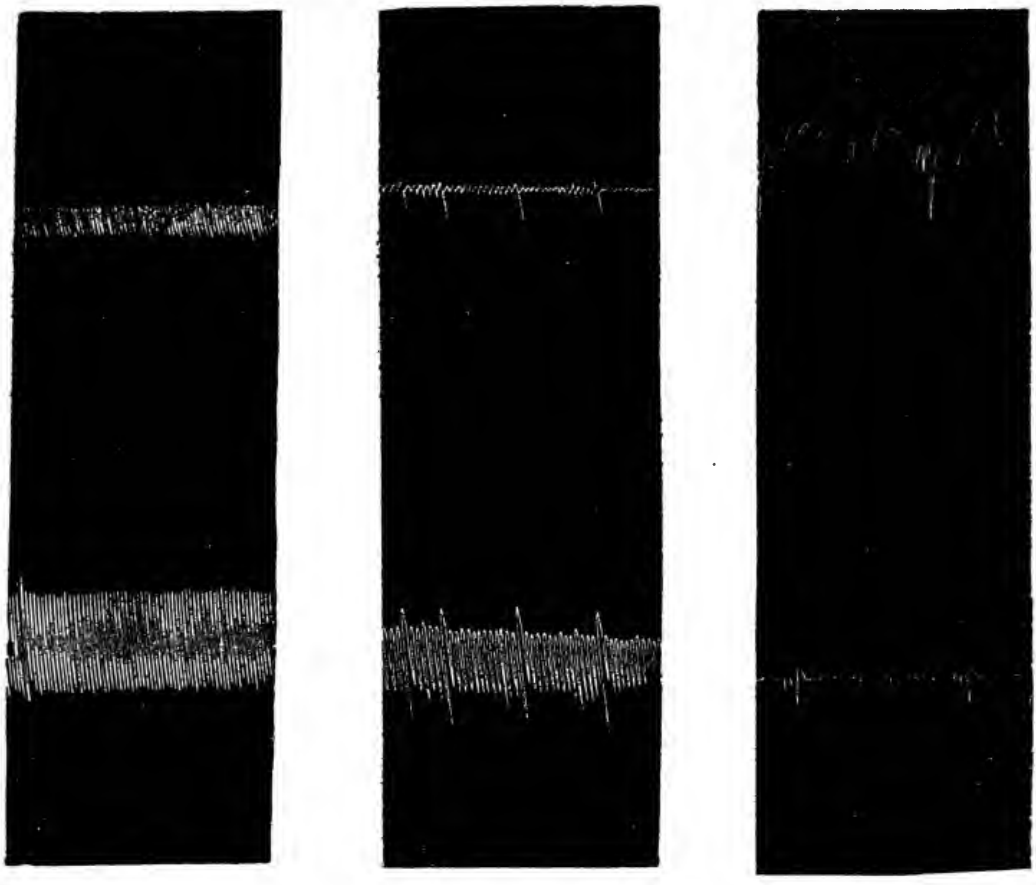

Fig. 4

Part 1. Respiration after laminectomy.

Part 2. Respiration after section of the dorsal roots in the thoracic and lower cervical regions.

Part 3. Respiration after section behind the posterior corpora quadrigemina. Note the Cheyne-Stokes respiration. Upper tracing represents costal, lower abdominal respiration.

Sherrington (13), in his work on decerebrate rigidity, describes the persistent tonic spasm which occurs in certain groups of muscles after section of the brain stem in front of the corpora quadrigemina. The groups of muscles which are contracted are the retractors of the head

and neck, the muscles of the tail, the extensors of the elbow, knee, shoulder and ankle—the antigravity muscles. The spasm depends on the integrity of the dorsal spinal roots and appears not at all, or only imperfectly, in the limbs of which the corresponding dorsal nerve roots are divided. Section at that level of the corpora quadrigemina also does away with decerebrate rigidity, a fact which offers further confirmation that certain fibers of the dorsal spinal nerve roots have end stations at this level.

CONCLUSIONS

In summarizing the effects upon the respiratory movements of section of the dorsal roots of the spinal nerves and at the level of the posterior corpora quadrigemina, my findings are:

1. Section of the dorsal roots of the thoracic and cervical spinal nerves results in a diminution or cessation of active costal respiration. The effect of section of both thoracic and cervical nerves is a more marked diminution of costal respiration than after section of the thoracic roots alone. After section of the thoracic roots, abdominal respiration remains unchanged and there is no marked alteration in the respiratory rate.

2. Section of the brain stem below the anterior corpora quadrigemina results in a slower, deeper form of respiration than normal somewhat similar to the most severe effects which follow double vagotomy. Abdominal respiration is more prominent than costal.

3. Section of the dorsal roots of the spinal nerves after section into or behind the posterior corpora quadrigemina produces no more severe effect than section of the posterior corpora quadrigemina alone.

4. Section of the posterior corpora quadrigemina subsequent to section of the dorsal roots of the spinal nerves produces an effect on respiration somewhat greater than when the dorsal roots alone are sectioned.

5. The general relationship of afferent to efferent spinal nerve roots which Sherrington (14) describes obtains also in the afferent and efferent intercostal roots.

I wish to express my thanks to Professor F. H. Pike of this department for his valuable suggestions and criticisms of this work.

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VITA

Helen Copeland Coombs was born in St. Joseph, Missouri, July 25, 1891. She graduated from the Yonkers High School and entered Barnard College in 1907. She received the degree of Bachelor of Arts from Barnard College in 1911; the degree of Bachelor of Science from Teachers College in 1914; and of Master of Arts from Columbia University in 1915. Since that time she has carried on research work in experimental physiology in the Department of Physiology of Columbia University. She is now Research Assistant in that department.

Her publications are:

The Postural Activity of the Abdominal Muscles of the Cat. By F. H. Pike and Helen C. Coombs. American J. Physiol., vol. xlii, p. 395, 1917.

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